

Preliminary results from small μ -pixel CdZnTe arrays

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ABSTRACT

We have evaluated 2 small μ -pixel (0.65 mm) Cadmium -Zinc-Telluride arrays with thickness of 1 and 2 mm that were fabricated for MSFC by Metorex and Baltic Science Institute (Riga, Latvia). Each array was optimized for temperature and collection bias and was then exposed to Cadmium 109 , Am 241 and Fe 55 laboratory isotopes to measure the energy resolution for each pixel. The arrays were then scanned with a finely μ -collimated X-ray beam, of width 100 μ m, to examine pixel to pixel and inter μ -pixel charge collection efficiency. Preliminary results from the array tests are presented.

Key Words: Cadmium -Zinc-Telluride, pixelated detectors.

1. BACKGROUND

Cadmium-Zinc-Telluride (CdZnTe) detectors are particularly attractive for high γ -energy applications due to their low band gap (1.5 eV) and high Z (48, 52). Their high bulk resistivity ($\sim 10^{11}$ ohm-cm), and good mobility-lifetime product has rendered them the leading detector material under development for room temperature gamma-ray astronomy between 5 to 500 keV.

Of particular interest there, is the use of CdZnTe as a future focal plane detector for a balloon-borne hard γ -ray astronomy telescope under construction at MSFC¹. The hard γ -ray region is particularly interesting, as it is a transition region in which source mechanisms change from thermal to non-thermal processes such as synchrotron radiation and inverse Compton scattering. This region is, however, relatively unexplored. At lower energies, focusing telescopes have revolutionized the field delivering sensitivities 5 orders of magnitude greater than non-focusing instruments of the same collecting area. At higher energies the ever-smaller γ -ray reflection angles lead to very tiny effective areas and to date no hard γ -ray telescope has been flown. Our approach to developing such a telescope is to nest arrays of very-shallow-graze angle, iridium-coated mirrors to build up useful collecting areas for ground-breaking observations up to 75 keV.

For these telescopes, CdZnTe is a promising focal plane detector material. Its high density and effective atomic number ensure that high efficiencies can be obtained with thin (\sim mm) detectors and that, as the absorption products are well contained, the material can provide good spatial resolution. To examine how well this works in practice, we commissioned a series of small pixelated arrays with the intention of examining such effects as pixel to pixel gain, energy resolution and efficiency variations, and inter μ -pixel charge collection. The following sections contain some preliminary results from our study of two of the arrays.

2. DETECTORS

Table-1 and Figure 1, below, show the main features of the tested detectors.

Table1: Detector Characteristics

Detector	D1(1mm)	D2(2mm)
Detector Material	CdZnTe	CdZnTe
Crystal Dimension (mm)	5x5	5x5
Thickness (mm)	1	2
Pixel dimension (mm)	.65x.65	.65x0.65
No of pixels	16	16
Distance between pixels mm	0.1	0.1
Operating temperature	-22 DegC	-22 DegC
Operating Voltage	-400	-900

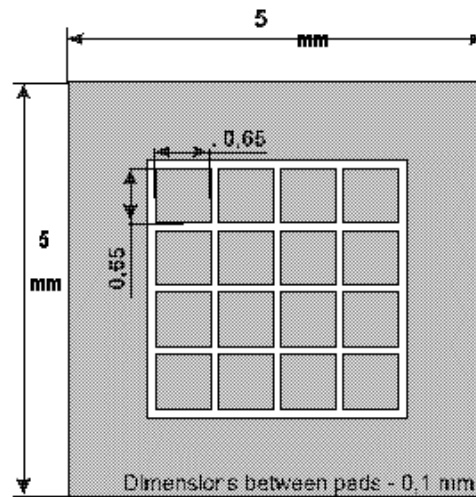


Figure1: Layout of the pixel of the CdZnTe arrays. Each array is a matrix of 4x4 pixels, each of area 0.65x0.65 mm². Between each pixel is a 0.1 mm gap.

The detectors were each delivered in the form of compact units that contain the following:

- A small sealed vacuum chamber with thermoelectric cooler housing the 16 pixel CdZnTe crystal. The cooler is capable of cooling down to -40 degC.
- The electronics for temperature control, 16 un-cooled preamplifiers and network for high voltage filtering.
- An ion pump, attached to the vacuum chamber.
- A beryllium window positioned above the cathode side of each array for x-ray illumination.

In addition, a common, stand-alone, unit provided power to the preamplifiers, high voltage to the ion pump, biased the detector array and control for the cooler.

The crystal preparation involved traditional technologies. The pad contacts were made with a lift-off photolithographic process, with gold deposition through the lifted window and then gold contact wires were epulse bonded to the pads.

3. EVALUATION

We have measured various detector parameters for each pixel including energy resolution, photopeak efficiency and response uniformity along the surface using lab isotopes of ^{55}Fe (5.9 keV), ^{241}Am (59.9 keV), ^{109}Cd (22 & 88 keV) and an X-ray machine equipped with a copper target emitting X-rays at 8 keV. With the X-ray head mounted on an XY table, we used an ultrafine beam (~100 microns) to probe variations across pixels and any inter-pixel effects.

Our initial evaluation concentrated on the following:

- A study of detector noise as a function of bias voltage and operating temperature
- A study of the effect of operating voltage and operating temperature on the detector resolution and the charge collection efficiency by using ratio of photopeak to continuum.
- A study of the stability of the detector when operated continuously for about 24 hours.
- A study of the energy resolution, output, and uniformity of each pixel of the detector array
- A study of the behaviour of the detectors when illuminated in the inter-pixel gap.

4. RESULTS (1-MM-THICK DETECTOR)

4.1 Study of Noise vs. Temperature

This study was carried out by operating the detector at the recommended bias voltage (-400 volts) and then decreasing the temperature from room temperature (+25 °C at MSFC in June) to the recommended -22 °C. The noise was observed on a MCA, and showed a fairly large decrease between +25 and +15 °C, and then a small continuous reduction after that. This noise variation is shown in Figure 2.

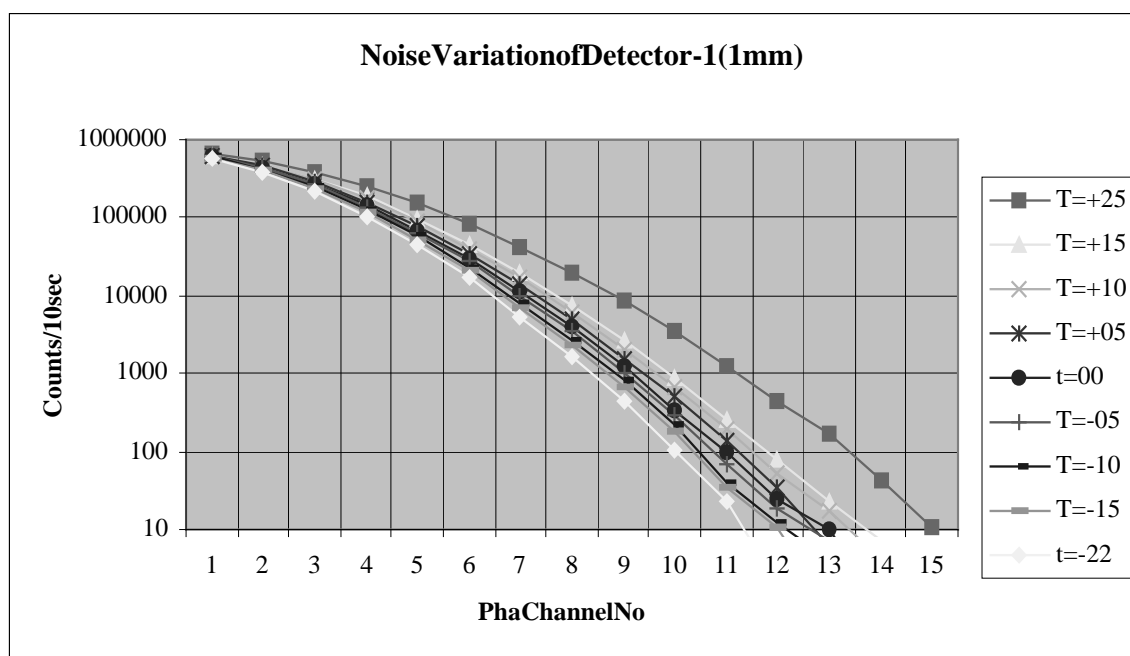


Figure 2: Shows the variation of noise measured by PHA as the operating temperature is lowered. The largest change takes place when temperature is lowered from room temperature (+25) to +15 °C.

4.2 Study of Operating Voltage and Operating Temperature

We have studied the effect of bias voltage and temperature on the performance of the detector. We have found that the operating temperature has no significant effect on the resolution or ratio of the photopeak -count to continuum -counts at 60 keV. Therefore, the detectors could be operated at room temperature without loss of their good characteristics. This is shown graphically in figure 3. We did observe a strong effect of pulse shaping on these parameters as seen in Figure 4, where a different time constant was used resulting in poorer overall resolution, but slightly higher photopeak to continuum value.

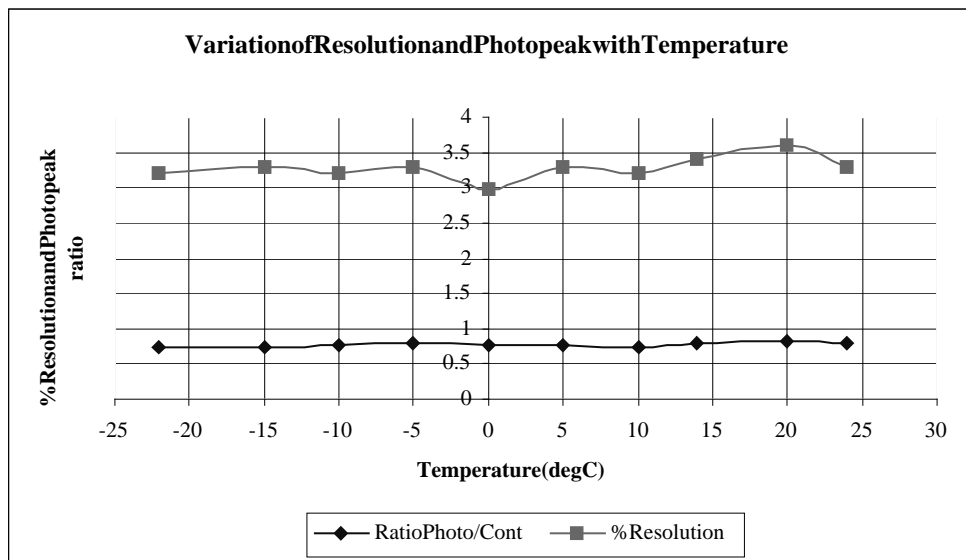


Figure3: The variation of resolution and photopeak efficiency with operating temperature at 60 keV. No significant variations are evident.

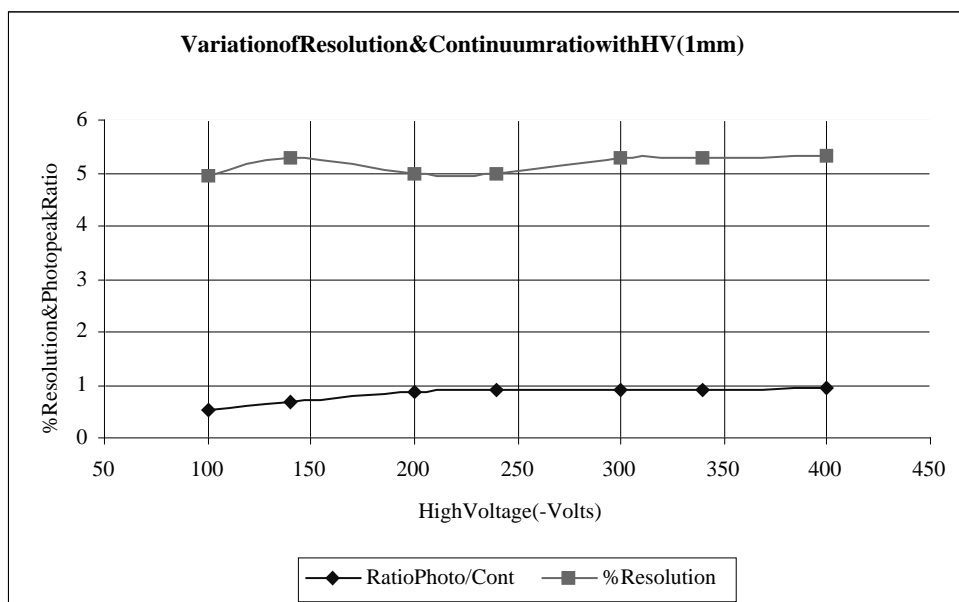


Figure4: The variation of resolution and photopeak efficiency with operating voltage. No significant improvement is seen above 200V.

Figure 4 shows the effect of variation of bias voltage on the resolution and the ratio of the photo count to continuum-counts at 60 keV. It is noticed from the figure that the operating voltage has no significant effect on the resolution or the ratio of the photo peak count to continuum counts above 200 volts.

4.3 Time Variations

Table 2 below shows the record of measurements spread over 8 hours. Output from each pixel was measured using a Pulse Height Analyzer (PHA) and Fe ⁵⁵ radioactive source. It is clear from the table that none of the pixels showed any significant gain variation over this period.

Table-2: Pulse height of the PHA peak when pixels were irradiated by Fe ⁵⁵ (6 keV)

Time	8:15hrs	9:15hrs	10:15hrs	11:15hrs	12:15hrs	13:15hrs	14:15hrs	15:15hrs	16:15hrs
Pixel-1	61	62	62	62	62	62	62	62	62
Pixel-2	63	62	63	62	63	63	62	63	63
Pixel-3	63	65	64	63	63	64	65	63	63
Pixel-4	61	61	61	61	62	61	62	61	61
Pixel-5	64	63	64	65	64	64	64	64	63
Pixel-6	62	62	62	63	62	62	63	63	63
Pixel-7	63	64	63	64	64	64	64	65	63
Pixel-8	63	63	64	63	64	63	63	63	63
Pixel-9	58	58	57	59	58	58	58	58	58
Pixel-10	62	62	62	62	62	63	63	63	63
Pixel-11	61	60	61	61	62	60	62	61	61
Pixel-12	61	62	62	62	62	62	61	62	62
Pixel-13	60	61	61	61	61	60	61	61	61
Pixel-14	61	61	62	62	62	62	61	62	62
Pixel-15	58	58	58	57	57	59	58	58	59
Pixel-16	62	62	62	63	63	62	62	62	62

We have also investigated possible low-energy (5.9 keV) efficiency variations over a 24-hour period. These data are shown below in Figure 5. It is evident from this figure that the array is quite stable over this timescale.

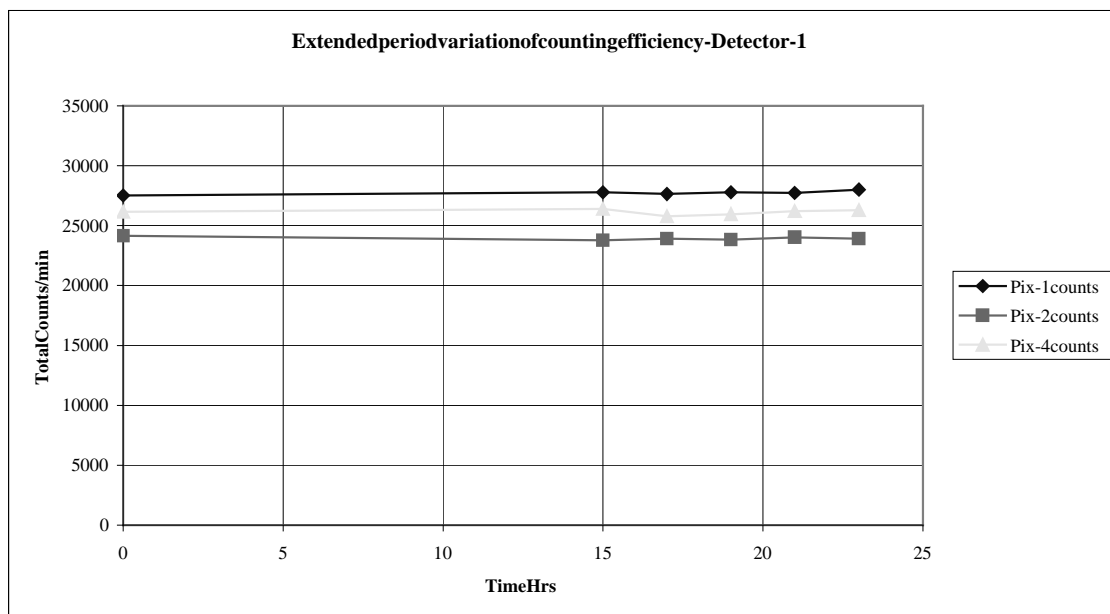


Figure 5: Photo peak counts versus time at 5.9 keV.

4.4 Study of Resolution of Each Pixel (detector 1 – 1mm)

The resolution of each pixel is shown in Figure 6, below, at energies of 6, 22 and 60 keV with optimum pulse shaping. It can be seen that except for pixel 3 that has a larger amount of noise, the majority of the pixels show a uniform behaviour. Figure 7 shows the ratio of the photo peak to continuum at these three energies, whereas similar pixel to pixel uniformity is evident. It is interesting to note that these ratios are the same at 22 keV and 60 keV.

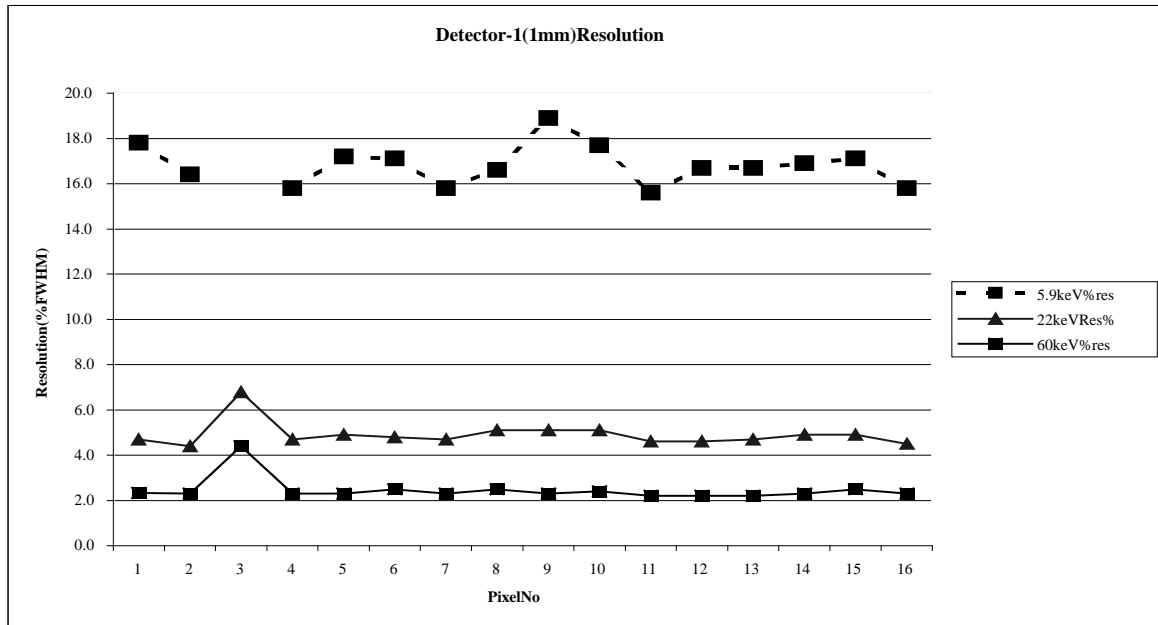


Figure 6: Monitoring the resolution of each pixel of the 1 mm detector reveals a uniform behaviour except for (noisy) pixel 3.

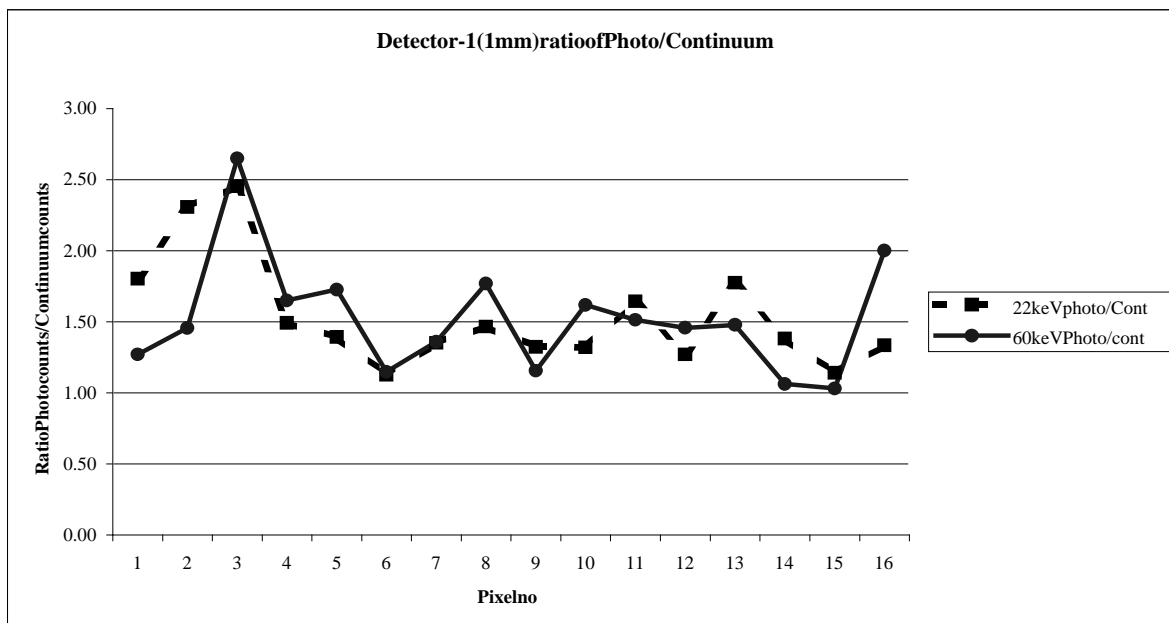


Figure7: The ratio of photopeak to continuum for each pixel at three energies.

4.5 Scans Across the Pixel Surfaces and Inter-Pixel Gaps

We have performed detailed studies of the uniformity of the pixel through comparison of the constructed size with observed (active) size and recovery of the signal from photon that are incident in the gap between two pixels. These aspects are discussed separately in the next paragraphs. To facilitate this study we selected a middle row that was surrounded by pixels on all sides. Then we moved the X-ray beam from one end of a pixel (9) to the other end of third pixel (14) that is located at the edge of the detector. In between these two pixels, pixel 12 was situated.

Figures 8 and 9 show the total counts, continuum counts and photopeak counts that were recorded using a PHA. It is evident that the active size of the pixel matches with that specified by the manufacturer and that within the pixel the response is uniform. The counts in the continuum rise at both ends for pixel 9. This rise is due to charge sharing between pixel 9 and its near neighbor which places counts formerly in the photopeak to counts into the continuum.

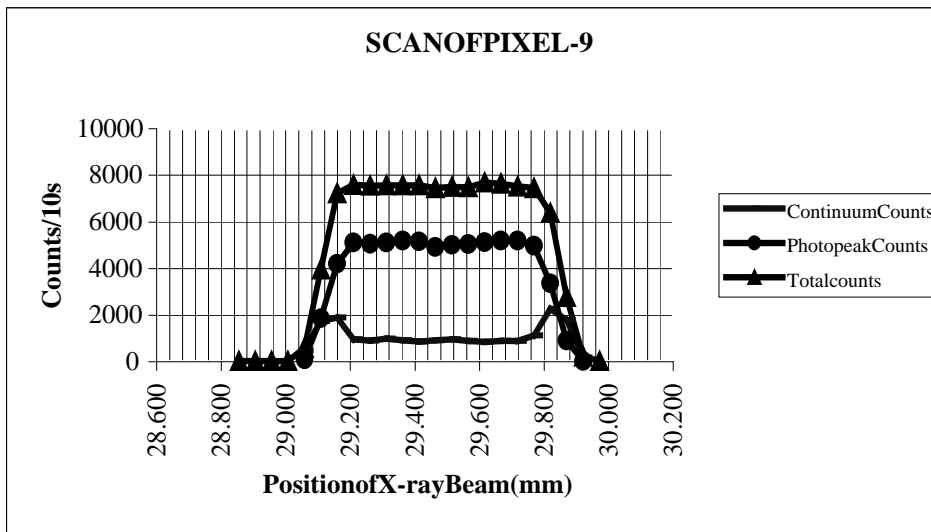


Figure8: Counts from pixel 9 when beam moves from pixel 12 to 9. One can notice that the continuum (that includes low amplitude pulses) shows a rise in counts at both ends. This rise is due to events shared by neighboring pixels.

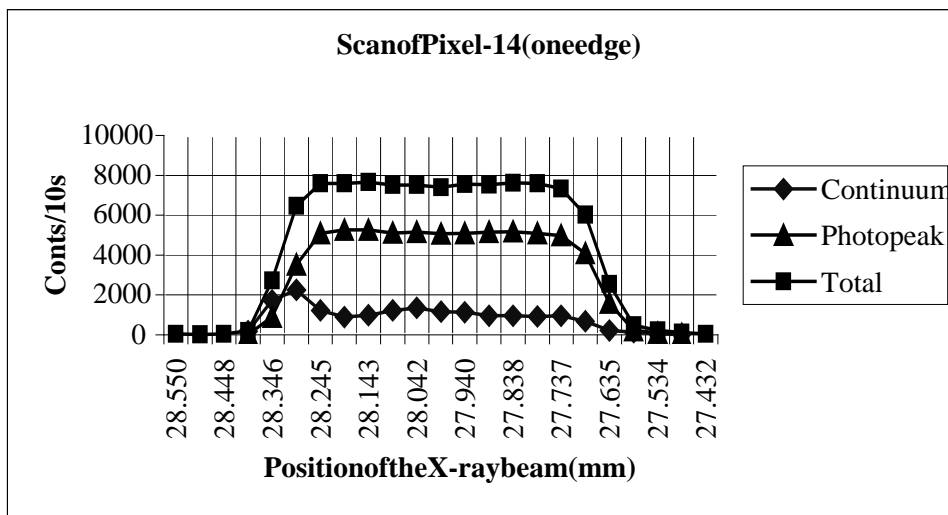


Figure9: Counts from pixel 14 when the beam moves from pixel 12 to 14 and ends outside the edge of the detector.

4.5.1. Recovery of photons interacting with the gap

When the total counts from all the pixels, counted independently then summed, are plotted as a function of beam position the count rate profile shown in figure 10 is generated. This graph shows the summed counts from the three pixels that were scanned. The increase in the total at ~29.1 mm and 28.3 mm is due to double counting of events that are shared between pixels.

To investigate if any counts are lost between pixels, we have summed the (simultaneous) output of adjacent pixels and performed a fine -beam x -ray scan. These results are shown in Figure 11. It is evident that the charge falling between pixels can be fully recovered by summing the signals from the sharing pixels.

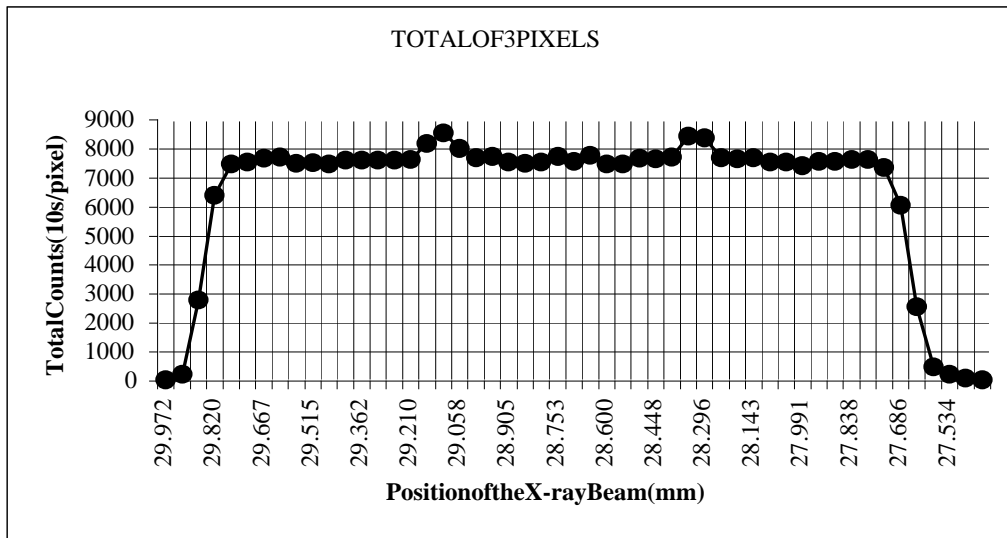


Figure10: Summed (independent) counts from the three pixels that were scanned. The two peaks indicate where charge is shared and the events are double counted.

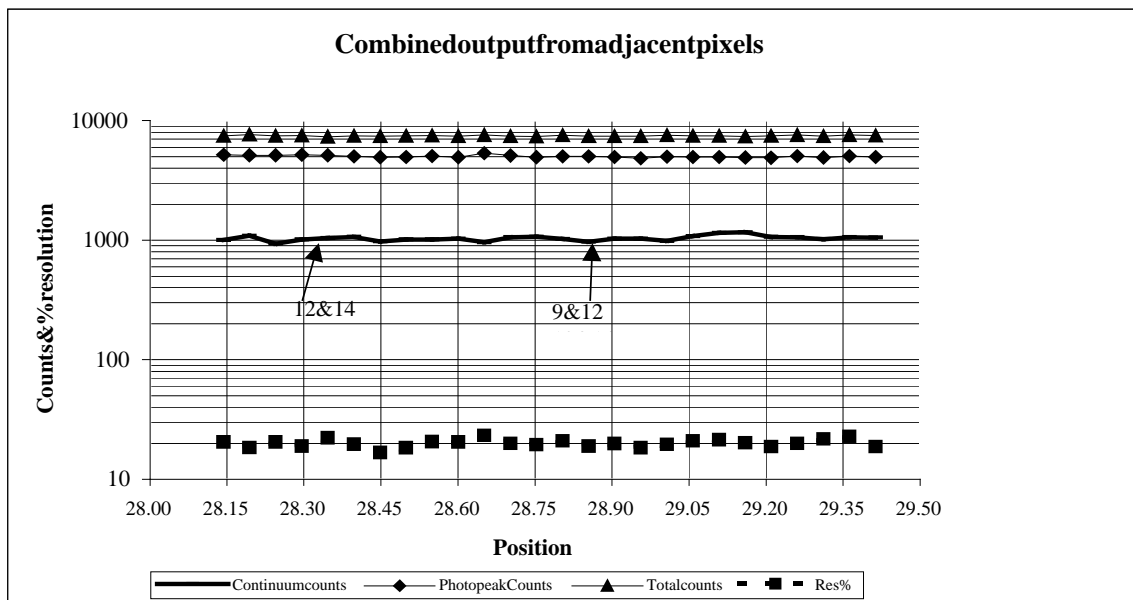


Figure11: Combinedoutputfromadjacentpixelsshowsthatnoinformationislostbetweenpixelsat8keV.

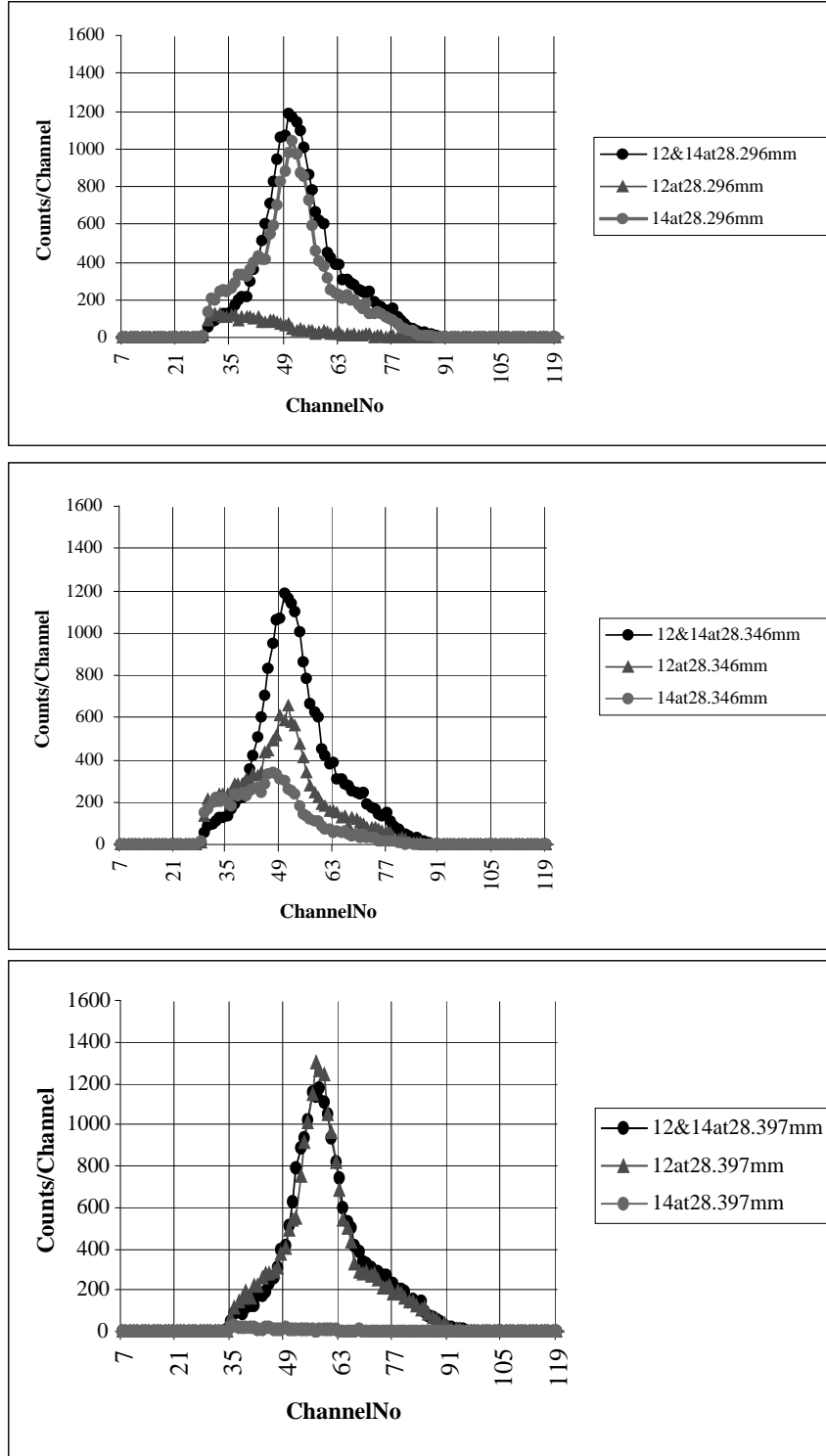


Figure12: Summedandindividualspectraontwoadjacentpixels(12&14)astheX-raybeamisscannedacrosstheinter-pixelgap.

ThesesequenceofspectrainFigure12showtheindividualandsummedspectraontwoadjacentpixelsasthefine -beam8KeV sourceisscannedacrosstheinter -pixelgapfromtheedgeofpixel14(top)totheedgeofadjacentpixel12(bottom). The chargesharingregionisapproximatelyequaltothegapwidth(100micron)andfullreconstructionispossiblethrough summation.

5.RESULTS(2 -MM-THICKDETECTOR)

Asimilarsetofstudiesisbeingcarriedoutwiththe2 -mm-thickarrays,butareyet tobecompleted.Figure13showsthe variationofresolutionandratioofphotopeaktocontinuum.Itisevidentthatthedetectorcouldbeoperatedwithabiasjust above600voltswithoutsignificantchangeoftheperformancecharacteristics.Themeasurmentofresolutionofeachpixel of2mmarrayispresentedinfigure14.Ourtestsindicatedthatseveralpixelsadnon -uniformresponsewithinthepixelarea whenscanned,anddidnotappeartoshowsizesconsistentwiththeirfabricateddimensions.Wear ecurrentlyinvestigating theseeffects.Finally,Figure15showsthevariationofphotopeakefficiencyattwoenergiesforeachofthepixelsofthe2 mmthickarray.Thesedataarealsostillunderanalysis.

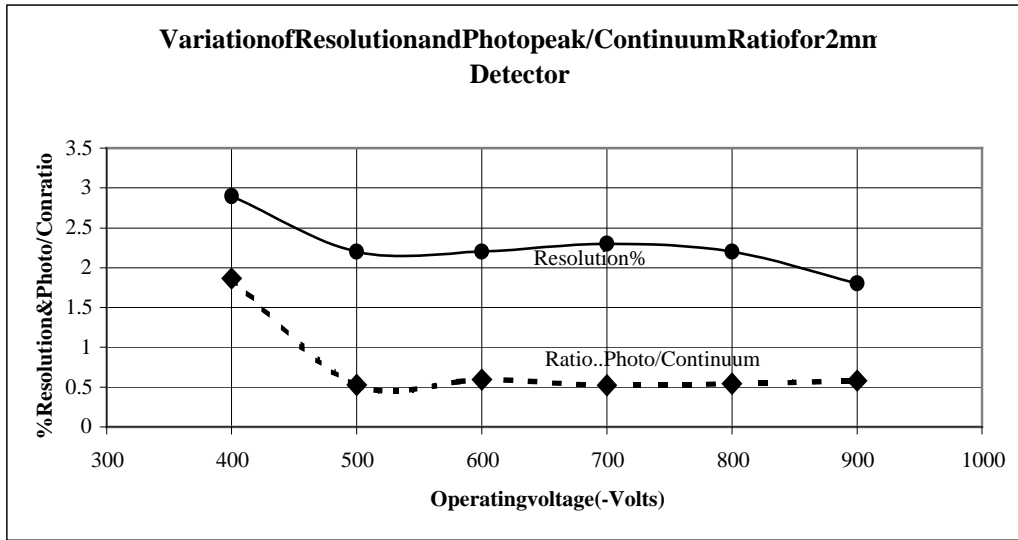


Figure13: Variation of resolution and photo peak to continuum ratio with operating voltage at 60 keV.

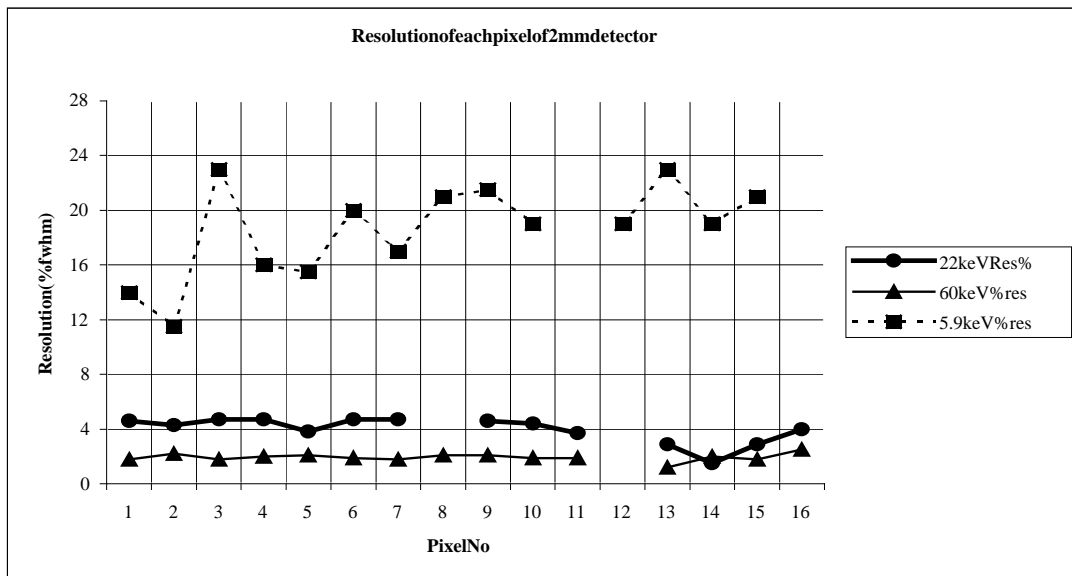


Figure14: Resolution of each pixel of the 2 -mm detector array at 6, 22 and 60 keV.

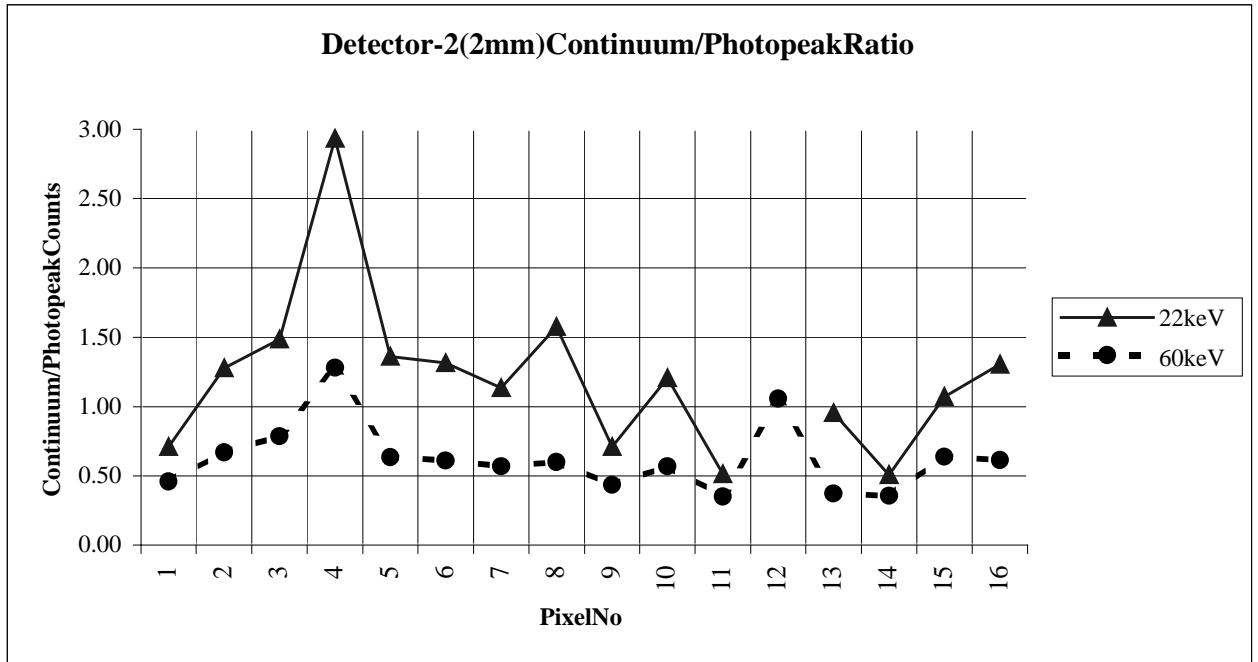


Figure15: Continuum to photopeak ratio for each pixel of the 2 -mm thick array at 22 and 60 keV

6. CONCLUSIONS

Our preliminary study shows that:

- The 1 -mm detector array showed good energy response and uniformity and had good stability over 24 hour periods.
- The full charge of the photons incident between the gaps of the pixels is recoverable without any loss.
- Signal sharing between pixels is limited to those events in the inter -pixel gap only (after removing finite beam size.)
- The 2 -mm-thick detector also exhibited good energy resolution, but needs further investigation regarding uniformity of response within each pixel.

REFERENCES

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